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GROSS CHEMICAL CHANGES OF HUMAN WASTE UNDERGOING THERMAL DECOMPOSITION

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INTRODUCTION

Detailed characterization of the volatilization of human wastes represents the major work for this contract period. Gas analyses on the volatilization chamber effluent were made, using an Orsat Apparatus. Accurate analysis of the combustion and volitilization chamber effluent will begin upon delivery of the infrared gas analyzer for CO_2 measurement; in the meantime, the Orsat Apparatus and the MSA carbon monoxide indicator will be used to delineate the region where more accurate data are desirable. Preliminary work on growing algae (Chlorella) with the ash from the volatilization chamber was commenced. The major effort in the future will be directed toward product recovery from the incineration process.

An MSA carbon monoxide indicator, with a range of 0.005 to 0.15% was purchased for gas analysis of the effluent from the volatilization and combustion chamber. A cooling coil and a lucite tank were fabricated to serve as a condenser for the gas effluent. A series of algae culture apparatus was set up for preliminary work on volatilization chamber ash utilization by algae.

A condenser to reduce the temperature of the gas effluent from the volatilization and combustion chamber is necessary for the protection of the MSA carbon monoxide indicator and the Beckman infrared carbon dioxide gas analyzer which will be used for gas analysis from the incineration process.

LABORATORY WORK

Solubility and carbon content of the residue after ignition at 400° C were determined for different rates of air supply to the volatilization chamber. Information on the relationship between residual weight and oxygen supply and between residual carbon and oxygen supply was obtained with the volatilization chamber operated at 200°, 300° and 400° C. The volatilization chamber was operated in two stages with respect to temperature, and the carbon content of the ash was determined after each stage. Carbon monoxide and carbon dioxide analyses of the volatilization chamber effluent were made, using an Orsat Apparatus.

*This research was conducted in accordance with the "Principles of Laboratory Animal Care" of the National Society for Medical Research.

A series of experiments to determine if the solid residue remaining after the volatilization of human wastes contained nutrients adequate for algal growth was undertaken. Samples of the residue and supplemental nutrients were added to distilled water to make up a culture media for algal growth. The media made up in this manner were dispensed into flasks and inoculated with Chlorella. Cell counts were made on the cultures two different times after inoculation to determine if any growth was occurring. Since these were preliminary experiments, the cultures were not aerated, no attempt was made to control the temperature, and the lighting for the cultures was not adequate to allow optimum growth rates.

It was expected that the residue would not contain a carbon source for the algae and that it might be inadequate in nitrogen, phosphorous, or one of the micronutrients required by the algae. Also, the possibility that some material toxic to the algae might be present in the residue was recognized. Therefore, it was planned to provide supplemental nutrients as it became apparent they were needed and to employ ethylenediamine tetraacetic acid (EDTA) as a chelating agent to suppress any toxicity which might be present.

RESULTS AND DISCUSSION

Table I shows the characteristics of the raw urine and feces mixture. Information on the solubility of the ash are tabulated in Table II. The residual weight and carbon content of the ash with respect to time for different operating conditions of the volatilization chamber are summarized in Tables III(a), III(b) and III(c). Table IV indicates the distribution of carbon in the various forms. Results on the qualitative growth characteristics of Chlorella are shown in Table V.

The solubility of the ash, in HCl, was found to be independent of the operating temperature of the volatilization chamber and rate of air supply for the range from 2 to 15 l/m. The solubility in water exhibits somewhat the same trend, but the magnitude of the solubility is lower. Comparison of these results with those presented earlier indicates that the magnitude of the solubility is lower for the volatilization chamber ash than for the muffle furnace ash. This difference will be investigated further by obtaining comparable solubility data for the volatilization chamber and the muffle furnace. Considerably higher rates of air supply to the volatilization chamber (30 - 45 l/m) will be used in an attempt to increase the solubility to a magnitude which is equal to or greater than the values observed with the muffle furnace. The solubility in acid and water for the volatilization chamber ash was 0.12 and 0.08, respectively; for the muffle furnace, 0.18 and 0.13 gm per gm standard sample. This difference is not explained by the variation in the

raw sample used, as sample D was a common sample. Mechanical carry-over of finely divided particles of oxides by the air stream is also unlikely because the solubility is relatively independent of the rate of air supply. A single series of tests, not shown in Table II, indicates that the solubility is related to the degree of complete combustion. This would indicate that the organic compounds contain a moderate amount of inorganic elements other than oxygen and hydrogen which are converted into soluble material.

TABLE I

CHARACTERISTICS OF RAW SAMPLES OF URINE AND FECES[1]

Sample	% Carbon[2] dry basis	% Solids[3] wet basis	C/A[4] dry basis	C/V[5] dry basis
B_2	48.8	n.a.[6]	5.53	0.535
C_2	32.5	6.50	1.43	0.419
D_2	42.1	3.89	2.53	0.506
Average	41.1	5.20	3.16	0.487

[1]Each entry in the table represents the arithmetic average of two or three determinations.

[2]Per cent carbon by weight was determined from carbon and hydrogen analysis.

[3]Per cent solids by weight was determined by drying at 103° C.

[4]The weight ratio of carbon/ash was determined at 850° C.

[5]The weight ratio of carbon to volatile matter was determined at 850° C.

[6]Not available.

TABLE II

SOLUBILITY OF RESIDUE, VOLATILIZATION CHAMBER*

Furnace Temperature °C	Raw Sample	Air Supply l/m	Solubility Distilled Water	Solubility 0.02N-HCl
400	C_2	15.13	0.07	0.13
400	C_2	4.16	0.08	0.15
400	B_2	2.03	0.03	0.09
440	B_2	2.03	0.05	0.12
400	D	2.03	0.10	0.12
388	D	7.50	0.10	0.14
388	D	7.50	0.11	0.12
388	D	7.50	0.09	0.11
388	D	7.50	0.11	0.14

* Solubility is expressed in gm dissolved per gm standard sample.

TABLE III(a)

WEIGHT AND CARBON REMAINING VS TIME

400° C, 15.13 l/m air supply, 2 gm sample C_2

Item	Time (minutes) 2.5	11	22	37	60	120	180	241
Weight Remaining, per cent	50.9	28.3	27.8	27.1	26.2	24.8	24.2	23.4
Carbon Remaining, per cent	31.3	15.0	9.65	7.59	6.96	6.35	2.58	1.22

400° C, 4.16 l/m air supply, 2 gm sample C_2

Item	Time (minutes) 3.5	13.5	40.5	62.5	125	184	248
Weight Remaining, per cent	49.2	33.1	30.0	28.5	28.0	26.7	25.9
Carbon Remaining, per cent	35.4	17.7	14.9	8.36	7.16	3.44	2.81

400° C, 2.03 l/m air supply, 2 gm sample B_2

Item	Time (minutes) 3	14	27	50	100	240
Weight Remaining, per cent	68.7	32.5	27.3	17.8	14.1	11.2
Carbon Remaining, per cent	66.8	32.2	28.8	11.3	6.45	1.51

TABLE III(b)

WEIGHT AND CARBON REMAINING VS TIME

400° C, 2.03 l/m air supply, 2 gm sample D

Item	Time (minutes) 3	14	27	50	100	240
Weight Remaining, per cent	76.2	40.3	37.6	35.2	34.8	26.7
Carbon Remaining, per cent	76.6	38.6	32.8	——	26.3	13.8

300° C, 15.13 l/m air supply, 2 gm sample D

Item	Time (minutes) 4	10	40	60	120	240	(hours) 10	27	75	142
Weight Remaining, per cent	73.3	66.8	51.2	49.2	48.3	45.7	37.7	30.4	24.5	23.3
Carbon Remaining, per cent	83.5	69.0	52.3	49.6	48.4	44.0	31.8	21.0	9.05	7.16

300° C, 15.13 l/m air supply, 2 gm sample D

Item	Time (minutes) 4	10	40	60	120	240	(hours) 10	27	73	138
Weight Remaining, per cent	72.5	67.0	54.1	51.9	47.3	44.1	38.8	32.5	26.6	22.7
Carbon Remaining, per cent	81.0	73.2	57.8	52.6	47.9	41.6	25.2	19.6	10.0	7.27

TABLE III(c)

200° C, 15.13 l/m air supply, 2 gm sample D

Item	Time (minutes)					Additional time at 600° C (minutes)		
	4.5	30	90	210	450	5	10	15
Weight Remaining, per cent	98.5	85.4	79.5	75.5	70.1	24.1	20.6	18.7
Carbon Remaining, per cent	98.7	—	89.3	69.1	41.4	6.61	2.03	0.12

TABLE IV

CARBON BALANCE, VOLATILIZATION CHAMBER

Volatilization Chamber: 400° C
2 gm sample D

Sample Number	Volatilization Chamber Temperature °C[2]	Air Supply l/m	Carbon, gm				
			C_o[1]	C_{co_2}[2]	C_{co}[2]	Particulate[3]	Residue[1]
1	388	7.50	0.813	—	—	—	0.088
2	388	7.50	0.844	0.14	0.0	0.57	0.130
3	388	7.50	0.881	0.14	0.0	0.50	0.240
4	388	7.50	0.844	0.14	0.07	0.44	0.193
5	400	15.13	0.823	0.20	0.0	0.61	0.016
6	400	4.16	0.868	0.11	0.0	0.74	0.021
7	400	2.03	0.873	0.18	0.0	0.68	0.018
8	400	4.16	0.844	0.10	0.06	0.66	0.021

Notes: 1 From carbon and hydrogen analysis
2 Orsat gas analyses
3 (C_o - C_{co_2} - CO - Residue)

TABLE V

ALGAL GROWTH ON RESIDUE FROM INCINERATION OF HUMAN WASTES

Culture Number	Components of Medium				Cell Counts		Time of Culture (days)	Generation Time (days)
	Residue (mg/l)	Dextrose (mg/l)	EDTA (mg/l)	Urea (mg/l)	Initial (cells/ml)	Final (cells/ml)		
I-1	30	10	—	—	Not Available	0	10	—
I-2	60	10	—	—		0	10	—
I-3	90	10	—	—		0	10	—
I-4	120	10	—	—		0	10	—
II-1	30	10	10	10	1.26×10^5	1.21×10^7	7	1.06
II-2	60	10	10	10	2.53×10^5	1.53×10^7	7	1.18
II-3	90	10	10	10	2.53×10^5	1.45×10^7	7	1.20
II-4	120	10	10	10	4.84×10^5	1.18×10^7	7	1.52
III-1	30	—	—	10	1.94×10^6	1.55×10^7	7	2.33
III-2	30	—	—	10	1.35×10^6	1.50×10^7	7	2.10
III-3	30	—	10	—	1.43×10^6	1.81×10^6	7	—
III-4	30	—	10	—	8.00×10^5	1.77×10^6	7	—
III-5	30	10	—	10	1.22×10^6	1.96×10^7	7	1.74
III-6	30	10	—	10	1.18×10^6	1.52×10^7	7	1.89
III-7	30	10	10	—	2.23×10^6	1.89×10^6	7	—
III-8	30	10	10	—	9.68×10^5	3.78×10^5	7	—
III-9	30	—	10	10	2.19×10^6	2.40×10^6	7	—
III-10	30	—	10	10	1.22×10^6	1.94×10^6	7	—

The weight and carbon remaining versus time for different rates of air supply and different volatilization temperatures demonstrate that the rate of carbon loss from dried samples of urine and feces mixture can be regulated. The data indicate that regulation of the rate of carbon loss can be accomplished by varying the volatilization temperature or the rate of air supply, the former having a more pronounced influence than the latter. This flexibility in regulation permits variation of the detention time in the combustion chamber without changing its geometry and enables a reasonably uniform rate of carbon input to the combustion chamber. The latter advantage allows flattening out peak loads on the combustion chamber, thus making a small physical size possible.

The carbon content of the ash from the volatilization chamber is approximately ten times the values observed in the muffle furnace, both compared at constant weight. This indicates that higher rates of air supply to the volatilization chamber can improve the combustion process, and data are being collected using 30-45 l/m air supply. Table III(c) shows that low temperature operation of the volatilization chamber (200° C) followed by high temperature operation (600° C) gives carbon removal comparable to that obtained with a muffle furnace operating in a free atmosphere.

The data presented in Table IV show that 75 per cent of the carbon leaves the volatilization chamber in the form of particulates. Due to the choice of procedure for calculating the amount of particulates, this class includes all carbon containing compounds other than CO and CO_2. More accurate information can be obtained when the infrared gas analyzer becomes available.

The results of the series of algal culture experiments are presented in Table V. In the first four cultures varying amounts of the residue were provided and dextrose was added as a carbon source. The absence of growth in any of these cultures indicates that the residue is deficient in some nutrient other than carbon. In the second four cultures the supplemental nutrients were dextrose (as a carbon source) and urea (as a nitrogen source) with EDTA added as a chelating agent. Since good growth was observed in all of these cultures it is evident that the residue contains all required nutrients for Chlorella except carbon and nitrogen. In the last ten cultures varying combinations of dextrose, urea and EDTA were used to supplement the residue. The results of these experiments indicate that the presence or absence of EDTA in the medium had very little effect on the growth of the algae and, thus, that the residue does not contain appreciable quantities of material which is toxic for Chlorella.

Apparatus is now being set up so that the further experiments on algal growth may be carried out in cultures for which adequate lighting and temperature control is available. Experiments will be run to determine the maximum concentration of the residue which will be tolerated by the algae and if the carbon and nitrogen in the gaseous combustion products from the incineration of human wastes may be utilized by algae.